Fiber Optic Cable Assemblies for Space Flight Applications III: Characterization of Commercial Cables for Thermal Effects

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Introduction

This is the third paper in a series of white papers addressing the issues associated with the usage of optical fiber cables in space flight applications.[1-2] These experiments which aim to characterize commercially available optical fiber cables, are crucial for deciding which cables are appropriate for which space flight missions, based on their environmental performance. In addition to determining which cables are best for space flight applications, the methods and parameters by which these cables are "preconditioned" is also under study such that the problem of thermally induced cable component shrinkage can be alleviated. This problem of cable component shrinkage has become an issue associated with all optical fiber cable on the market today and presents a calibration and reliability problem[1]. This paper addresses the issue of thermal effects and preconditioning of optical fiber cables to increase their usabilility in a variety of space flight missions.

Optical Fiber Cables Tested

For this thermal characterization, five fiber optic cable configurations were tested: one from W.L.Gore, two from Brand Rex, and two from RIFOCS (manufacturer Northern Lights). All cables chosen for this testing were chosen based on their potential for use in space flight applications. These cables were designed to be commercially available (all but the OC1614, which was made for space station) but were also space flight, ruggedized, cable configurations. One of the Brand Rex cables included in this study, the OC1008, is actually a discontinued item but was included for comparison purposes since this cable was used for both the TRMM and XTE missions. The W.L. Gore cable was designed to be used in the -55°C to +125 °C thermal environment and the Brand Rex space station cable OC1614 was designed for the -100°C to +75°C, though most of the other candidates do not have such a wide temperature rating. Another aspect to note about the OC1614 is that based on the configuration described below which includes a polyimide coated fiber, it is very likely that the cable could be operated all the way to 200°C. Brand Rex does confirm that although the OC1614 was made to the SSQ-21654 specification it could be capable of temperatures well beyond the upper limit required by Space Station of +75°C . Table 1 describes the configurations of the cables tested with some details about their dimensions and specified thermal environments. The cables listed in Table 1 with the exception of the OC1008, are in fact available or will be available, with other types of optical fiber beyond what was listed and tested here. Brand Rex, W.L.Gore and Rifocs have communicated the intention of using these cable configurations with various coated, glass, fibers to satisfy market needs.for a variety of optical cable products. Therefore, the products listed here are only an example of the family of cables that are available using these configurations. The cables listed and tested here were chosen based on availability of the cables at the time of this testing.

Table 1: Cable Candidate Configuration Summary

Vendor Cable Part #	Cable Configuration	Fiber Type	Secondary Buffer	Strength Members	Outside Jacket	Outer diameter	Thermal rating
W.L. Gore FON1004	Tight Tube with Metal braid over GoreTex buffer	Single mode, 1310/1550 nm acrylate buffer	Gore Tex Expanded PFA	Kevlar	FEP Fluoropolymer	2.5 mm	-55°C to +125°C
Brand Rex OC1614 (SSQ-21654 Rev. B)	Tight tube	Multimode 100/140/170 micron hermetic seal/ polyimide buffer	FEP Teflon	Teflon impregnated fiber glass	FEP Teflon	2.1 mm	-100°C to +75°C
Brand Rex OC1008	Loose tube	Multimode 100/140/500 micron acrylate buffer from corning now discontinued	Hytrel	Teflon impregnated fiber glass	ETFE Tefzel	2.77 mm	- 55°C to +85°C
RIFOCS H06	Tight tube	Multimode 62.5/125/250 micron	Hytrel	Kevlar	Tefzel	2.4 mm	-40°C to +95°C
RIFOCS HL1	Tight tube	Single mode, 1310/1550 nm acrylate buffer	Hytrel	Kevlar	Tefzel	2.4 mm	-40°C to +95°C

Thermal testing environmental parameters:
The test was conducted to determine the amount of thermally induced shrinkage of the cable components and the resulting optical performance for a temperature range of -55°C to +125°C. Most of the cable tested were not rated for the extremes of -55°C to +125°C due to the rating of the acrylate coating on the fiber which is usually only rated to +85°C. Because of this, it is important to note that all the optical cable candidates with the exception of the W.L. Gore FON1004, were taken beyond their thermal specifications. The ramp rates for all of the thermal testing was 2°C/min with dwells of 28 minutes per temperature extreme.

The thermal testing was conducted in two parts. During part one of the testing, all cables were cycled and measured after each 8 cycle session for dimensional shrinkage in the longitudinal direction only, and some optical measurements were made. Part two of this testing was focused on the optical performance of these cables (with most of them being taken well outside of their thermal specifications), both during cycling and after. The overall optical fluctuations that occured during the cycling were used as a characterization of the thermal expansions and contractions due to the CTE of materials used in the configurations. The post test optical measurements should be indicative of how the static shrinkage of materials in the cable configuration have affected the optical performance of the cable permanently.

Table 2: Test Plan and Measured Parameters

Candidate	Color	Length	# of Samples	Fiber Type	Outer diam	Test Temp Range	Test	Termination connector/ test wavelength
W.L.Gore Prototype II FON1004 (8.4 m)	yellow	3 m	3	SM (7.0/125)	2.53 mm	-55 to +125	- 2 samples length test only, - 1 sample optical test	ST, SM 125 micron
Brand Rex Space Station OC-1614 (9.85 m)	dark purple	3 m	3	MM (100/140)	2.23 mm	-55 to +125	- 2 samples length test only, - 1 sample optical test	ST, MM 1300 nm
Brand Rex OC-1008** (leftover on spool)	purple	3 m	3	MM (100/140)	2.62 mm	-55 to +125	- 2 samples length test only, - 1 sample optical test	ST, MM 140 micron 1300 nm
Northern Lights HL1 (Rifocs) (50 m)	plum	3 m	3	SM (8.8/125)	2.36 mm	-55 to +125	- 2 samples length test only, - 1 sample optical test	ST, SM 125 micron 1300 nm
		10 m	4			-55 to +125	- 2 samples length testing, - 2 samples optical test	
Northern Lights H06 (Rifocs) (50 m)	plum	3 m	3	MM (62.5/125)	2.33 mm	-55 to +125	- 2 samples length test only, - 1 sample optical test	ST, MM 125 micron 1300 nm
		10 m	4			-55 to +125	- 2 samples length testing, - 2 samples optical test	

Table 2 lists the cables being tested and specifies the measured outer diameter of the cable configurations prior to testing. Also listed is the actual amount of cable available for this testing. The last column lists the connector type used as well as the testing wavelength. It was not ideal to use ST connectors (instead of FC's) for this evaluation but for the purposes of compatibility between existing test equipment and available patch cables, these connectors were chosen.

The cables were measured in length prior to any testing and re-measured after each 8 thermal cycle session. The total number of cycles for thermal testing part one, was 72 cycles total. Therefore, 9 sessions were conducted and 10 measurements per cable were made.

Test Results Part I: Cable Component Shrinkage as a Result of Thermal Cycling

The test results of the thermally induced length shrinkage tests are in Tables 3 and 4. The data in Table 3 is graphed in Figure 1. The length measurements were made following each 8 cycle session and compared to the measured length value prior to the session. The numbers in bold in each column represent the point at which the length shrinkage remained below .1%. The largest amount of cable jacket shrinkage was seen with the W.L.Gore FON1004 and the smallest amount of jacket shrinkage was seen with the Brand Rex OC1614. By the end of the 48th cycle it appeared that most of the cables, with the exception of the OC1008, had begun shrinking less than .1%. This result is similar to the results from the study published last year in reference 2. It also appears that by the end of the 24th cycle, a good deal of the total shrinkage has been accomplished (see Figure 1). Since the values from sample set 2 are similar to that of sample set 1 only the data from sample set 1 is represented graphically, for clarification, in Figure 1.

Table 3: Summary, % shrinkage results per cycle session from thermal testing of sample set 1

Total Thermal Cycles	W.L Gore FON1004	Brand Rex OC1614	Brand Rex OC1008	RIFOCS H06	RIFOCS HL1
8	1.98	**0.05**	0.77	1.42	1.82
16	0.60	0.00	0.30	0.22	0.10
24	0.09	0.03	0.24	0.14	**0.07**
32	0.09	0.00	0.17	0.00	0.03
40	0.22	0.00	0.14	0.10	0.03

48	**0.04**	0.00	0.10	**0.00**	0.03
56	0.00	0.03	0.10	0.03	0.00
64	0.00	0.00	**0.03**	0.00	0.00
72	0.00	0.00	0.07	0.00	0.03
Total % shrinkage	**2.99**	**0.12**	**1.90**	**1.90**	**2.12**

Table 4: Summary, % shrinkage results per cycle session from thermal testing of sample set 2

Total Thermal Cycles	**W.L Gore FON1004**	**Brand Rex OC1614**	**Brand Rex OC1008**	**RIFOCS H06**	**RIFOCS HL1**
8	1.14	**0.07**	0.77	1.28	1.82
16	0.47	0.00	0.27	0.25	0.12
24	0.37	0.03	0.24	0.10	0.03
32	0.24	0.03	0.10	**0.07**	0.00
40	0.34	0.00	0.17	0.07	0.14
48	0.10	0.00	0.07	0.00	**0.00**
56	0.21	0.00	0.10	0.00	0.00
64	**0.07**	0.00	**0.07**	0.03	0.00
72	0.03	0.00	0.03	0.07	0.03
Total % shrinkage	**2.94**	**0.13**	**1.80**	**1.87**	**2.13**

There was no visible damage that occurred as a result of taking most of the cables outside of their respective thermal specifications. It is interesting to note that the FON1004 and both RIFOCS cables had jacket shrinkage but the kevlar and other buffer materials did not shrink. In the thermal tests conducted and reported in reference 2, all of the cable components would shrink back, exposing the coated optical fiber.

RIFOCS has outlined a preconditioning procedure for their cables: 8 thermal cycles with 60 minute dwell at +90°C and 15 minutes at +10°C, with ramp rates of less than 10°C/minute. They do not state what amount of shrinkage can be expected after this preconditioning has been performed. RIFOCS also offers this preconditioning as part of the product for an additional charge. As evidenced here the majority of the cable jacketing shrinkage does in fact occur as a result of the first 8 cycles. For HL1, 85% of the shrinkage occurred in the first 8 cycles. For H06, sample 1 decreased in length 75% in the first 8 cycles and sample 2 had decreased by 69% after a total of 72 cycles. However, these tests do not confirm the preconditioning procedure used by RIFOCS since the parameters used are not the same.

The inclusion of the OC1008 was done to provide a reference for comparison of the test data to data for a flight cable used in the past on space flight missions. The effect that the thermally induced jacket shrinkage has on the optical performance of these cables is presented in part two of this paper.

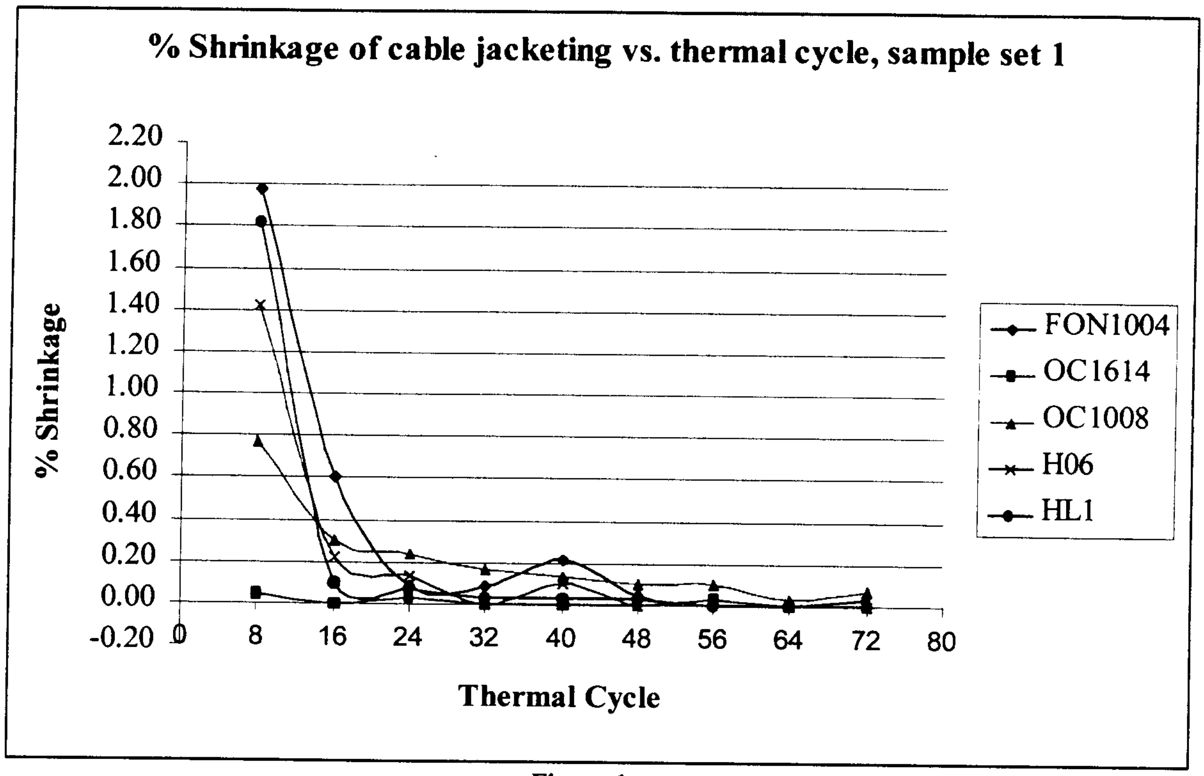

Figure 1

Test Results Part II: Optical Performance During and After Thermal Cycling.

Experiments are currently being conducted on the optical performance of the cables mentioned above. The report is in progress and once completed, will include comparisons between optical losses and cable component length shrinkage. Part II should be completed by the end of November 1999. Once completed a new version of this report will be submitted.

References:

1. Melanie N. Ott, Jeannette Plante, Jack Shaw, M. Ann Garrison-Darrin, "Fiber Optic Cable Assemblies for Space Flight Applications: *Issues and Remedies,*" Paper 975592 SAE/AIAA 1997 World Aviation Congress, October 13-16, Anaheim, CA.

2. Melanie N. Ott, "Fiber Optic Cable Assemblies for Space Flight II: Thermal and Radiation Effects," Photonics For Space Environments VI, Proceedings of SPIE Vol. 3440, 1998.